eCook Tanzania Prototyping

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Executive Summary

This report summarises the findings from the **prototyping carried out in Tanzania**, with the aim of informing the development of a **battery-supported electric cooking concept, eCook**. It is part of a broader programme of work, designed to identify and investigate the opportunities and challenges that await in high impact markets such as Tanzania.

The eCook Tanzania Mark 1 Prototype consists of **1.2kWh LiFePO4 battery storage, an 800W inverter/charger, a 30A solar controller and set of energy-efficient electric cooking appliances**. It could be charged from solar panels and/or the grid, making it a **hybrid PV/Grid-eCook system**. It was sized to allow a small family (2-3 people) cooking efficiently using energy-efficient cooking practices to be able to do the majority of their cooking. For peaks in demand (many relatives coming to visit) or dips in supply (very cloudy days and/or blackouts lasting longer than a day), it would need to be supported by an alternative stove.

The eCook Tanzania prototype has been (and continues to be) very successful in **demonstrating the concept of battery-supported cooking to a broad range of stakeholders**, from future potential users to policy makers. Future demonstration prototypes should also have 2 modes: one that allows more technical people to see inside and another that shuts away the gubbins and allows the user to get on with cooking.

Figure 1: The eCook TZ Mark 1 Prototype at a workshop for a select parliamentary committee on energy in Dodoma.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

The prototyping carried out in Tanzania showed that in 2018, **many of the basic components required to build a cost-effective and technically optimised eCook system were still not available**. In particular, higher capacity lithium ion batteries and DC cooking appliances were very specialised pieces of equipment that required direct importation. The total cost for all the components came in at 1,480 USD, however there is significant scope for optimisation. As a result, a **total cost of 500USD for a mass-produced unit in 2020 seems feasible**.

Establishing a **supply chain for larger scale (>10Ah) lithium ion batteries in East Africa will be key to achieving affordability**. Currently the only options are spare parts for SHS or importing directly from the factory in China. More insight is needed into the implications of charging LiFePO4 batteries with lead acid chargers. With the proliferation of lead acid batteries and chargers around the world today, there would be considerable benefit if it there were some compatibility, however the risks in terms of both safety and battery lifetime are not currently clear.

Future prototypes should use a single LiFePO4 battery pack with a BMS (Battery Management System) designed for C-rates of up to 2C. For safety reasons, LiFePO4 battery packs have a BMS built in to prevent over charging or over discharging. A single LiFePO4 battery pack with a single BMS is more robust than multiple units in parallel or series, as each battery is slightly different and each BMS will cut off supply at a slightly different point. The thin BMS cables supplied with the LiFePO4 batteries were a key weak point in the eCook TZ Mark 1 prototype, as they are designed for much lower currents. As a result, even if a LiFePO4 battery is supplied with conventional battery terminals, there may well be components inside the BMS that will fail at higher C-rates unless the battery has specifically been designed for this.

Future prototypes should aim to incorporate **similar state of charge indicators to mobile phones or laptops** (likely coulombic counting and learning algorithms to detect capacity from full cycles), which also use lithium ion batteries. Clearly communicating to users how much energy is left in the battery is vital to reduce the frustration of the battery running out half way through cooking. Measuring the state of charge of a lithium ion battery is more complicated than lead acid, as the voltage/stage-of-charge curve is much flatter.

The **development of DC cooking appliances** is another important next step. Inverters are expensive and bulky, adding another point of failure and making the whole system less efficient. They also limit the maximum power that can be drawn, therefore defining which appliances can be used and whether they can be used simultaneously or not. The relationship between C-rate and useful energy available from the batteries should be investigated further. Until DC cooking appliances become available, optimising the low voltage disconnect point for inverters could greatly increase usable storage. Even at a low C-rate (C/4), round trip efficiencies were lower than expected (63%). Further work is required to determine where other inefficiencies are and to optimise the system accordingly. Nonetheless, **a broad range of AC electric cooking appliances were available on the market** and insulated appliances were selected as they offer substantial energy savings, which can greatly reduce the size of the battery.

Future prototypes should focus on expanding the functionality of off-the-shelf insulated appliances to **increase the proportion of cooking that can be done on a single insulated appliance**. For example, by allowing the user to manually control the heat level in a rice/pressure cooker. **Insulated appliances can offer significant energy saving** and keep food warm once it is ready **s**, however they are bulky and are usually only supplied with a single pot. **The rice cooker, Electric Pressure Cooker (EPC) & thermo-pot were selected** for the eCook Tanzania Mark 1 Prototype. **Pressurisation is also important** for reducing cooking times on long boiling dishes such as beans. However, space is likely to be limited in the kitchens of poorer households, if there even is a dedicated kitchen space at all.

Voltage has a massive impact on power and therefore heat delivered by a cooking appliance. It is likely that consumers who have tried cooking with electric appliances on weak grids with fluctuating voltage will find the experience of cooking with battery-supported electricity via an inverter much more predictable, as an inverter produces a constant voltage (until the battery runs out!). However, **DC appliances are likely to cook faster when the battery is full** (13.6V for LiFePO4) than when empty (9-10V for LiFePO4). The power produced by a resistive heater is proportional to the square of the voltage, so a 25% drop in voltage equates to a 44% drop in power. Fortunately the relatively flat voltage/state-of-charge curve for LiFePO4 means the heat supplied by the stove is only likely to vary significantly when almost full or almost empty. Insulated appliances are also likely to mitigate this effect, as heat is retained inside the pot from earlier in the cooking process when the voltage was higher.

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Table of Contents

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1 Introduction

This report presents one part of the detailed in country research carried out to explore the market for eCook in Tanzania. In particular, this in country work aims to gain much greater insight into culturally distinct cooking practices and explore how compatible they are with battery-supported electric cooking. The report is rich with detail and is intended to provide decision makers, practitioners and researchers with new knowledge and evidence.

This report presents findings from the design, assembly and testing of a concept prototype to inform the future development of eCook within Tanzania. It is one component of a broader study designed to assess the opportunities and challenges that lay ahead for eCook in high impact potential markets, such as Tanzania, funded through Innovate UK's Energy Catalyst Round 4 by DfID UK Aid and Gamos Ltd. (https://elstove.com/innovate-reports/). A much deeper analysis of the data collected during this project was supported by the Modern Energy Cooking Services (MECS) programme, which included the writing of this report.

The overall aims of the Innovate project, plus the series of interrelated projects that precede and follow on from it are summarised in in *Appendix A: Problem statement and background to Innovate eCook project*.

1.1 Background

1.1.1 Context of the potential landscape change by eCook

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 billion people. This pervasive use of solid fuels and traditional cookstoves results in high levels of household air pollution with serious health impacts; extensive daily drudgery required to collect fuels, light and tend fires; and environmental degradation. Where households seek to use 'clean' fuels, they are often hindered by lack of access to affordable and reliable electricity and/or LPG. The enduring problem of biomass cooking is discussed further in *Appendix A: Problem statement and background to Innovate eCook project*, which not only describes the scale of the problem, but also how changes in renewable energy technology and energy storage open up new possibilities for addressing it.

1.1.2 Introducing ‘eCook’

eCook is a potentially transformative battery-supported electric cooking concept designed to offer access to clean cooking and electricity to poorer households (HHs) currently cooking on charcoal or other polluting fuels (Batchelor 2013; Batchelor 2015a; Batchelor 2015b). Enabling affordable electric cooking sourced from renewable energy technologies, could also provide households with sustainable, reliable, modern energy for a variety of other purposes.

A series of initial feasibility studies were funded by UK Aid (DfID) under the PEAKS mechanism (available from https://elstove.com/dfid-uk-aid-reports/). Slade (2015) investigated the technical viability of the proposition, highlighting the need for further work defining the performance of various battery chemistries under high discharge and elevated temperature. Leach & Oduro (2015) constructed an economic model, breaking down PV-eCook into its component parts and tracking key price trends, concluding that by 2020, monthly repayments on PV-eCook were likely to be comparable with the cost of cooking on charcoal. Brown & Sumanik-Leary's (2015), review of behavioural change challenges highlighted two distinct opportunities, which open up very different markets for eCook:

- PV-eCook uses a PV array, charge controller and battery in a comparable configuration to the popular Solar Home System (SHS) and is best matched with rural, off-grid contexts.
- Grid-eCook uses a mains-fed AC charger and battery to create distributed HH storage for unreliable or unbalanced grids and is expected to best meet the needs of people living in urban slums or peri-urban areas at the fringes of the grid (or on a mini-grid) where blackouts are common.

Figure 2: Pictorial definitions of ‘eCook’ terminology used in this report.

1.1.3 eCook in Tanzania

Given the technical and socio-economic feasibility of the systems in the near future, Gamos, Loughborough University and the University of Surrey have sought to identify where to focus initial marketing for eCook. Each country has unique market dynamics that must be understood in order to determine which market segments to target are and how best to reach them. Leary et al. (2018) carried out a global market assessment, which revealed Tanzania as the second most viable context for PV-eCook, due to its strong SHS industry and the fact that it is one of the world's biggest charcoal markets, creating several global deforestation hotspots.

The accompanying reports from the other activities carried out in Tanzania can be found at: https://elstove.com/innovate-reports/ and www.MECS.org.uk.

1.2 Aim

The aim of this study is to design, assemble and test an eCook concept prototype in Tanzania.

In particular, the objectives of the study are:

- To design the prototype around the needs and aspirations of Tanzanian cooks.
- To use the prototype to demonstrate the concept of cooking on battery-supported electricity to key stakeholders.

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2 Design specification

The eCook Tanzania prototype was designed to demonstrate that it is possible to cook on battery-supported electricity and to obtain feedback from end-users and other key stakeholders that could guide the design of the next generation of prototypes.

The design criteria were:

- Cost:
    - in the long-term, the components for similar systems should cost less than $500, but due to the restrictions on the availability of specialist components, this initial prototype could cost up to $2,000.
- Portability:
    - it should be possible to transport the entire system to events where it can be showcased.
    - During the Innovate funded research, these included the focus groups and stakeholder workshop, and beyond the initial research project, showcasing opportunities and other research opportunities.
- Safety:
    - it must not be dangerous for users with basic training and familiarity with off-grid systems to operate the system.
- Usability:
    - Cooks should be able to plug in off-the-shelf electric cooking appliances and use them in a similar way to if they were plugged into the main grid.
    - It should also be able to power low power DC appliances such as mobile phones or LED lights to demonstrate the additional energy services it can provide.
    - It should be possible to see how much energy is remaining in the batteries and how much has been used by each appliance.
    - It should be possible for TaTEDO staff with basic training to operate the system and for others to cook with it under their supervision.
- Energy storage:
    - it should be able to store enough energy to comfortably cook a meal for 5 people during a demonstration.
    - it should be able to charge from solar PV and the grid.
- Communication:

- It should be clearly laid out so that it is easy to explain what each of the components is and how they work together.

2.1 Appliance selection

THE RICE COOKER, ELECTRIC PRESSURE COOKER (EPC) & THERMO-POT WERE SELECTED FOR THE ECOOK TANZANIA PROTOTYPE. INSULATION CAN DRASTICALLY REDUCE ENERGY USE DURING COOKING & KEEP FOOD WARM ONCE IT IS READY. PRESSURISATION IS ALSO IMPORTANT FOR REDUCING COOKING TIMES ON LONG BOILING DISHES SUCH AS BEANS.

A range of appliances were tested during cooking diary study. Initial testing was carried out at the TaTEDO office, to select which appliances to showcase to participants, from which 6 appliances were selected:

1. Thermo-pot
2. Electric Pressure Cooker (EPC)
3. Hotplate
4. Induction stove
5. Rice cooker
6. Kettle

Participants were then given free choice from these 6 appliances. They were asked to select which 2 they would like to use to do all their cooking. The hotplate was the most popular appliance, however this may well have been because it had 2 plates, in contrast all the others had just one. Whilst the insulated appliances were initially less attractive to participants, after several weeks of testing the appliances at home and comparing experiences with neighbours and friends also participating in the study, many wished they had chosen the insulated appliances, as their expenditures were much higher. Whilst there is an initial behavioural change barrier to overcome with insulated appliances (keeping lid closed to keep heat in, only using a single pot), the impact on energy consumption is considerable. This makes them attractive to grid connected customers wanting to reduce their monthly expenditures. However, the role of insulation becomes even more important for battery-supported cookers, where the economics of the entire system depend heavily on the size of the battery.

Consequently, the appliances selected for the eCook Tanzania prototype were the rice cooker, EPC and thermo-pot. The following section distils some of the key findings from the appliance testing to justify this selection.

Table 1: Electrical appliance compatibility with key cooking processes (above) and popular Tanzanian dishes (below)

🟩 Standard
🟧 Possible
🟥 Impossible

Appliance	Fry	Steam	Pressure cook	Boil
Hotplate	🟩	🟩	🟩 *	🟩
Electric pressure cooker	🟧	🟩	🟩	🟩
Thermo-pot	🟥	🟧	🟥	🟩
Kettle	🟥	🟧	🟥	🟩
Induction cooker	🟩	🟩	🟩 *	🟩
Charcoal/firewood stove	🟩	🟩	🟩 *	🟩
Gas Hob	🟩	🟩	🟩 *	🟩
Rice cooker	🟧	🟩	🟥	🟩

Appliance	Rice	Ndizi	Nyama	Beans	Ugali	Vegetables
Hotplate	🟩	🟩	🟩	🟩	🟩	🟩
Electric pressure cooker	🟩	🟩	🟩	🟩	🟧	🟧
Thermo-pot	🟥	🟥	🟥	🟥	🟥	🟥
Kettle	🟥	🟥	🟥	🟥	🟥	🟥
Induction cooker	🟩	🟩	🟩	🟩	🟩	🟩
Charcoal/firewood stove	🟩	🟩	🟩	🟩	🟩	🟩
Gas Hob	🟩	🟩	🟩	🟩	🟩	🟩
Rice cooker	🟩	🟧	🟧	🟧	🟧	🟧

Table 2: Energy saving potential for key Tanzanian dishes.

🟩 Highly efficient
🟨 Moderately efficient
🟥 Highly inefficient

Appliance	Rice	Ndizi	Nyama	Beans	Ugali	Vegetables
Hotplate	🟨	🟨 Depends on pan				
Electric pressure cooker	🟩 Insulation and pressure					🟩 Insulation
Thermo-pot						
Kettle						
Induction cooker	🟨 Heats pan directly					
Charcoal/firewood stove	🟥 Heat lost up side of pan, hard to control					
Gas hob	🟥 Heat lost up side of pan					
Rice cooker	🟩 Insulation					

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2.1.1 Thermo-pot

- Typical applications
    - Boiling water for tea
- Technical specifications
    - 600-800W
    - 1.6-5litres capacity
    - 0.4-0.45kWh to boil 5litres
- Advantages
    - Insulation reduces power compared to kettle
    - Keeps contents warm (>50C) for up to 5 hours
- Disadvantages
    - Low power slow for lots of water (5 litres boils in 45 minutes)

2.1.2 Electric pressure cooker

- Typical applications
    - Curries, beans, stews, etc.
- Technical specifications
    - 700-1000W for 3-7litres capacity
    - 0.2-0.3kWh to cook beans for 4 people
- Advantages
    - Insulation & pressure vastly reduce energy requirement
    - Automated programs very convenient
    - Can fry, bake, boil, steam and pressure cook
- Disadvantages
    - Cannot see inside pot or stir whilst pressurized
    - Can only use a single size/shape pot

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2.1.3 Hotplate

- Typical applications
    - Almost universal
- Technical specifications
    - 700-2000W
- Advantages
    - Highly versatile – can work with almost any pot/pan
    - Most comparable to charcoal/gas
- Disadvantages
    - Cannot use round bottomed pans
    - Energy often lost around the edges of pot/pan if not good fit
    - Cannot bake or grill

2.1.4 Induction stove

- Typical applications
    - Almost universal
- Technical specifications
    - 1000-2000W
- Advantages
    - Heats pot directly, reducing heat loss
    - Highly controllable (power levels & timer)
    - Easy to clean
- Disadvantages
    - Cannot grill (except on griddle pan)
    - Can only use flat-bottomed steel pots

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2.1.5 Rice cooker

- Typical applications
    - Rice, soup, ugali etc.
- Technical specifications
    - 300-900W for 1-7litres capacity
    - 0.1-0.3kWh to cook rice for 4 ppl
- Advantages
    - Automatically controlled
    - Often insulated
- Disadvantages
    - Boiling & steaming only
    - No control over power

2.1.6 Kettle

- Typical applications
    - Boiling water for tea and bathing
- Technical specifications
    - 2000-2500W
- Advantages
    - Very quick to boil, so little time for heat to be lost
- Disadvantages
    - No insulation, so hot water not used immediately quickly cools
    - High power

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3 The eCook TZ Mark 1 Prototype

The eCook Tanzania Mark 1 Prototype consists of 1.2kWh LiFePO4 battery storage, an 800W inverter/charger, a 30A solar controller and set of energy-efficient electric cooking appliances (Table 3). It could be charged from solar panels and/or the grid, making it a hybrid PV/Grid-eCook system. It was sized to allow a small family (2-3 people) cooking efficiently using energy-efficient cooking practices to be able to do the majority of their cooking. For peaks in demand (many relatives coming to visit) or dips in supply (very cloudy days and/or blackouts lasting longer than a day), it would need to be supported by an alternative stove.

THE ECOOK TANZANIA MARK 1 PROTOTYPE COULD BE CHARGED FROM SOLAR PANELS AND/OR THE GRID, MAKING IT A HYBRID PV/GRID-ECOOK SYSTEM.

Table 3: Key performance metrics for the eCook Tanzania Mark 1 Prototype.

Metric	Performance
Maximum power	800W
Energy storage	0.8-1kWh
Cooking appliances	Thermo-pot Electric pressure cooker Rice cooker
Additional appliances	LED light USB mobile phone charger
Charging time	3-4 hours at 300W/25A
Power sources	Solar PV (300W panel recommended) Grid
Typical applications	Cooking most meals for a small family (2-3 people) on an everyday basis Cooking a single meal for 5-10 people during a demonstration

THE ECOOK TANZANIA MARK 1 PROTOTYPE WAS SIZED TO ALLOW A SMALL FAMILY (2-3 PEOPLE) COOKING EFFICIENTLY USING ENERGY-EFFICIENT COOKING PRACTICES TO BE ABLE TO DO THE MAJORITY OF THEIR COOKING.

Key strengths	Cooking anywhere, anytime for up to 6 years (when battery is expected to fail)
Key weaknesses	Heavy and bulky, can only use 1 appliance at a time, requires some training and behaviour change to use effectively

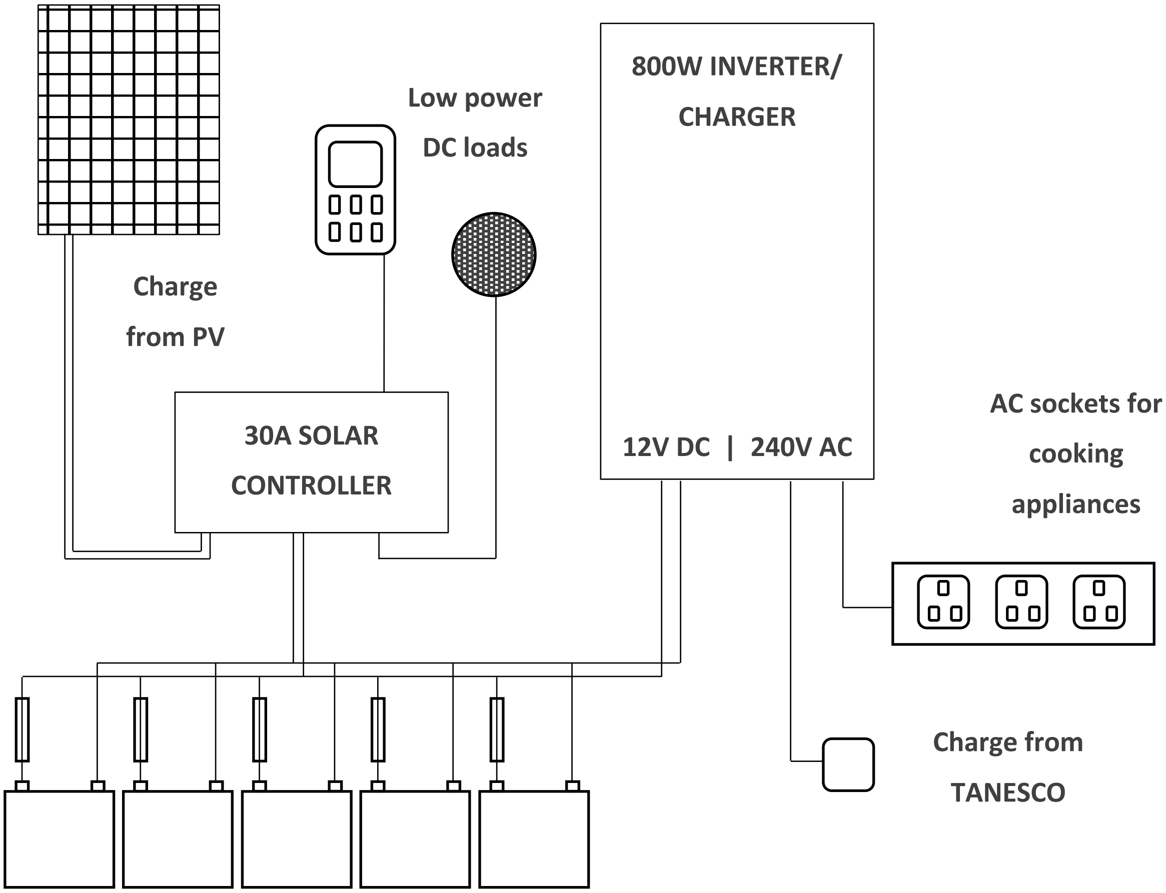
3.1 How it works

Electricity generated by the solar panels or drawn from the grid is stored in the LiFePO4 batteries, giving approximately 1kWh of useful energy for cooking. The solar charge controller monitors the state of charge of the batteries, slowing and then stopping charging when they become full as overcharging them can be dangerous. The inverter/charger does the same with the power coming from the grid.

DC loads can be connected via the solar charge controller and AC loads via the 3-way extension cable connected to the inverter/charger. DC loads are limited by the current rating of the solar charge controller (30A, i.e. 360W at 12V), although they could be connected directly to the batteries. Whilst AC loads are limited by the power rating of the inverter/charger (800W).

INVERTERS ARE EXPENSIVE & BULKY. THEY ADD ANOTHER POINT OF FAILURE & MAKE THE WHOLE SYSTEM LESS EFFICIENT. THEY ALSO LIMIT THE MAXIMUM POWER THAT CAN BE DRAWN & THEREFORE WHICH APPLIANCES CAN BE USED AND WHETHER THEY CAN BE USED SIMULTANEOUSLY OR NOT. THE DEVELOPMENT OF DC COOKING APPLIANCES IS AN IMPORTANT NEXT STEP.

Figure 3: Wiring diagram of eCook TZ Mark 1 Prototype.



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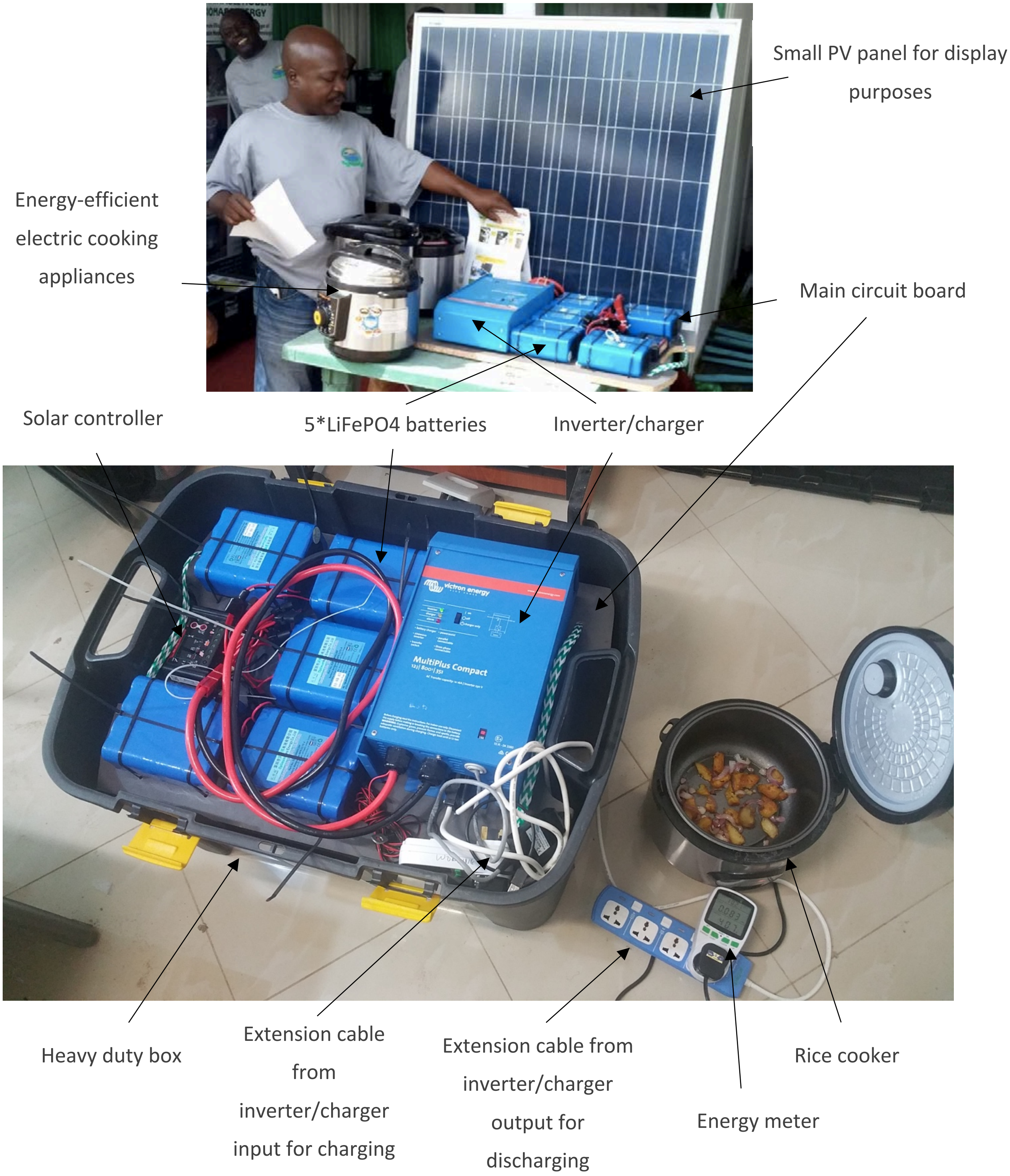

Figure 4: Annotated photos of eCook TZ Mark 1 Prototype key components.

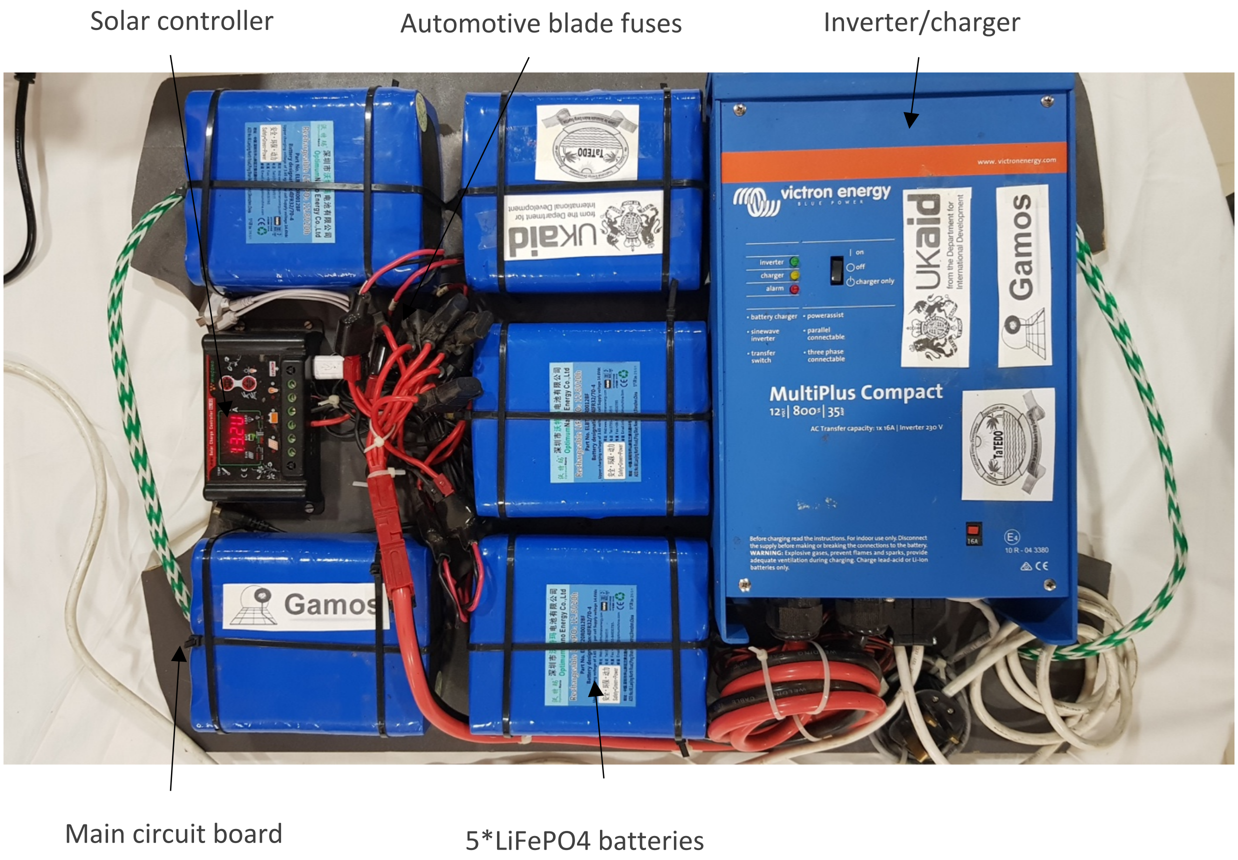

Figure 5: Top view of main circuit board.

3.2 Cost

ESTABLISHING A SUPPLY CHAIN FOR LARGER SCALE (>10AH) LITHIUM ION BATTERIES IN EAST AFRICA WILL BE KEY TO ACHIEVING AFFORDABILITY. CURRENTLY THE ONLY OPTIONS ARE SPARE PARTS FOR SHS OR IMPORTING DIRECTLY FROM THE FACTORY IN CHINA.

The total cost for all the components came in at 1,480 USD, however there is significant scope for optimisation. The LiFePO4 batteries were obtained as a spare part at a cost of 500USD/kWh, whilst factory gate prices in China are expected to fall to 200USD/kWh by 2020. An inverter will not be necessary in DC only systems, leaving just the solar or the AC charger depending upon the application. The number of appliances, size of the box and length of cabling/connections can also be reduced significantly by creating a single multifunctional battery-integrated DC cooking appliance. As a result, a total cost of 500USD for a mass-produced unit in 2020 seems feasible.

The main justification for component choice was availability. Over 20 solar suppliers were contacted in Dar es Salaam, however, none were able to supply lithium ion batteries of above 10Ah. The 12V 20 Ah LiFePO4 batteries used in the eCook TZ Mark 1 prototype were obtained on the good will of Orb Energy in Nairobi as a spare part for their Solectric 600 solar home system. These are the biggest lithium ion batteries they currently supply and are not usually sold separately. A similarly exhaustive search was carried out in Nairobi, however there were no other options.

However, it is expected that the availability of lithium ion batteries will improve in the future. Smaller batteries are already in use in a number of solar home systems and global prices are also dropping. At 120 USD per 20Ah unit, this equates to 500USD/kWh. Our cost modelling predicted factory gate prices of 200USD/kWh by 2020, however shipping, import taxes and other supply chain costs are likely to increase this significantly and should therefore be built into the modelling. In fact, on return to Nairobi, the price had increased to 200USD per unit, or 833USD/kWh. With no other option and a short deadline to build a new prototype for Kenyan stakeholders, there was no other choice but to purchase. Orb Energy cited reductions in the order quantity (just 50 units with a MoQ of 1,000 for the previous price) and lack of import tax exemptions for batteries shipped as spare parts instead of complete solar home systems.

Even after obtaining the LiFePO4 batteries, it was still very difficult to find LiFePO4 compatible charging equipment. LiFePO4 has a different charging regime to lead acid and the research team had received conflicting advice on the implications of charging LiFePO4 batteries with a lead acid charger. Some online sources state that LiFePO4 can be used as a drop-in replacement for lead acid, with the only implication being that they will never reach 100% SoC, which may impact cycle life[1]. In fact, subsequent experimentation has shown that for a single charge, a charger designed for lead acid can charge a LiFePO4 battery. However, this may have been due to the specific properties of the BMS of that particular battery pack that was able to regulate the charging voltage/current to the correct levels throughout the charging process, implying that not all LiFePO4 batteries may behave the same way. However, the long term impact on cycle life is still unclear and as the eCook TZ Mark 1 prototype was to be used by various members of the TaTEDO team during demonstrations, it was decided to opt for a more expensive inverter/charger designed specifically for LiFePO4 to avoid any potential safety issues. A Victron MultiComp inverter/charger with a LiFePO4 charging setting was obtained in Nairobi and a generic solar controller with a LiFePO4 setting was obtained in the UK. If LiFePO4 chargers had been available, buying a standard inverter (without charging functionality) and using both devices to charge and discharge the battery bank respectively would likely have been a cheaper option.

MORE INSIGHT IS NEEDED INTO THE IMPLICATIONS OF CHARGING LIFEPO4 BATTERIES WITH LEAD ACID CHARGERS. WITH THE PROLIFERATION OF LEAD ACID BATTERIES & CHARGERS AROUND THE WORLD TODAY, THERE WOULD BE CONSIDERABLE BENEFIT IF IT THERE WERE SOME COMPATIBILITY. WE NEED TO KNOW WHAT ARE THE RISKS OF DOING THIS IN TERMS OF BOTH SAFETY & BATTERY LIFETIME.

Importing equipment directly from China was considered, however due to the long shipping distance and factory lead time for producing samples, it was not a viable option for this project. Lithium ion batteries bigger than laptop size cannot currently be carried on an aeroplane, so must be shipped or transported overland. This not only makes prototyping much more difficult, but will also slow down the supply chain for commercial eCook products.

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[1] https://batteryuniversity.com/index.php/learn/article/types_of_lithium_ion

Table 4: Parts list for eCook TZ Mark 1 Prototype components.

Component	Specification	Brand	Supplier	No.	Unit cost	Total cost
Box	Tough Tote		Game	1	25 USD (60,000 TZS)	25 USD
Batteries	12V 20Ah LiFePO4	Optimum Nano-Energy	Orb Energy, Nairobi	5	120 USD (12,000 KES)	600 USD
Solar charge controller	30A LiFePO4 compatible		Amazon.co.uk	1	40 USD (30 GBP)	40 USD
Inverter/charger	800W LiFePO4 compatible	Victron	Centre for Alternative Technologies, Nairobi	1	600 USD (60,000 KES)	600 USD
Electric pressure cooker	850W, 4 litres	Singsung	Small electrical appliance store, Kariakoo	1	50 USD (120,000 TZS)	50 USD
Thermo-pot	750W, 3 litres	UMS	Small electrical appliance store, Downtown Dar es Salaam	1	55 USD (130,000 TZS)	55 USD
Rice cooker	700W, 5 litres	Von Hotpoint	Small electrical appliance store, Kariakoo	1	20 USD (50,000 TZS)	20 USD
Plug-in energy meters	3kW max power	Energenie	Amazon.co.uk	2	20 USD (15 GBP)	40 USD
Misc. components	13A 3-way extension cable, DC cables, screws, PowerPole connectors, 30A blade fuses & holders, cable ties, LED light, USB cable, rope, plywood mounting board	Various	Amazon.co.uk, Orb Energy, small hardware stores in Kariakoo and Downtown Dar es Salaam	Total for all	50 USD	50 USD
					TOTAL:	***1,480 USD***

3.3 Portability

The box could be carried by one strong person, but its size and weight leave considerable room for improvement. All items are contained within a tough plastic storage box and fastened down to prevent damage during transit on rough roads. The battery storage and power electronics were mounted onto a plywood board with either screws or cable-ties. The plywood board sits in the top of the box, leaving space for the appliances, food and utensils for demonstrations and basic tools for troubleshooting underneath.

3.4 Safety

The main safety risks were:

- Fire or explosion from short circuiting, over charging or over discharging of the battery or overloading of cables or components.
- Electric shock from live cables or components.

Mitigation measures included:

- Each of the 5 LiFePO4 battery was individually fused with 30A automotive blade fuses. The highest surge current measured was 90A, but the inverter limits continuous power to 800W and therefore a maximum of 76A (at 10.5V).
- All internal cabling was fastened down with cable ties to minimise the risk of cables catching and disconnecting when taking the main circuit board out of the box.
- All connections on the DC side were made with Anderson connectors which offer plastic insulation around terminals to prevent short circuits if they are accidentally disconnected.

THE BMS CABLES SUPPLIED WITH THE LIFEPO4 BATTERIES WERE A KEY WEAK POINT IN THE ECOOK TZ MARK 1 PROTOTYPE. FOR SAFETY REASONS, LIFEPO4 BATTERY PACKS HAVE A BMS (BATTERY MANAGEMENT SYSTEM) BUILT IN TO PREVENT OVER CHARGING OR OVER DISCHARGING. AS A RESULT, EVEN IF A LIFEPO4 BATTERY IS SUPPLIED WITH CONVENTIONAL BATTERY TERMINALS, THERE MAY WELL BE COMPONENTS INSIDE THE BMS THAT WILL FAIL AT HIGHER C-RATES UNLESS THE BATTERY HAS SPECIFICALLY BEEN DESIGNED FOR THIS.

- The prototype was tested by fully charging and discharging several times when first assembled. It was then used to cook lunch at the TaTEDO office for several weeks.
- Each LiFePO4 battery came with 1.5mm^2 cables coming out of the BMS. In a sealed environment (such as the storage box), they should carry a maximum current of 17.5A. With the above maximum current of 76A, this is 15A per battery, which is within this limit, assuming all of the 5 batteries are connected. Each battery is protected by a BMS, disconnects the load when the battery state of charge falls below a pre-set level (approximately 80% discharged, which equates to somewhere between 9 and 10V). During early testing, the low voltage disconnect of the inverter was set to 9.5V and the BMS in individual batteries would begin to trip, as each battery discharged at a slightly different rate. This then increased the current drawn from each other battery, causing the 1.5mm^2 wires to heat up. Fortunately the fuses started blowing on the remaining batteries, cutting off the current supply. This problem was resolved by increasing the inverter's low voltage disconnect to 10.5V, well above the threshold for the BMSs. As the voltage vs. state of charge curve for LiFePO4 is relatively flat until beyond 80% discharged, there useful energy sacrificed by doing this is relatively little. In practical terms, it sacrificed about 5 minutes of cooking time at full power, but still runs for more than an hour at 800W.

A SINGLE LIFEPO4 BATTERY PACK WITH A SINGLE BMS IS MORE ROBUST THAN MULTIPLE UNITS IN PARALLEL OR SERIES, AS EACH BATTERY IS SLIGHTLY DIFFERENT AND EACH BMS WILL CUT OFF SUPPLY AT A SLIGHTLY DIFFERENT POINT.

3.5 Usability

To cook with the prototype, the user simply switches on the inverter and plugs an appliance into one of the three sockets in the extension cable. The appliance will operate as if it were plugged into the grid, until the batteries run out. The inverter was programmed to cut off power well before there could be any risk of damaging the batteries through excessive discharge. To charge the batteries, the user must either

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

connect a solar panel to the solar charge controller or plug the inverter/charger into the grid. Charging time from the grid is 3-4 hours, at a rate of 25A or 300W. Therefore, a 300W solar panel in full sun could also charge the batteries in a similar timeframe.

The eCook TZ Mark 1 Prototype was paired with 3 energy-efficient cooking appliances obtained from retail stores in Dar es Salaam. All devices save energy by insulating the cooking pot and automatically controlling the cooking process:

- A 750W 3 litre thermo-pot – heats water at full power until it reaches 100C. Turns on at full power to top up heat when control system senses temperature has dropped significantly.
- An 850W 4l pressure cooker – cooks at full power until it reaches 120C, then turns off until the control system senses that the temperature is too low (somewhere between 100 and 120C) and turns on at full power again. Turns off when timer switch reaches the end. Decreases cooking time of long boiling dishes by approximately half by increasing the temperature inside the pot through pressurisation.
- A 750W 5l rice cooker – cooks at full power until the temperature in the pot rises above 100C, then automatically switches on to warm mode (approx. 40W).

INSULATED APPLIANCES CAN OFFER SIGNIFICANT ENERGY SAVINGS, HOWEVER THEY ARE BULKY AND ARE USUALLY ONLY SUPPLIED WITH A SINGLE POT. SPACE IS LIKELY TO BE LIMITED IN THE KITCHENS OF POORER HOUSEHOLDS, IF THERE EVEN IS A DEDICATED KITCHEN SPACE AT ALL. FUTURE PROTOTYPES SHOULD FOCUS ON EXPANDING THE FUNCTIONALITY OF OFF-THE-SHELF INSULATED APPLIANCES (E.G. ALLOWING THE USER TO MANUALLY CONTROL THE HEAT LEVEL IN A RICE/PRESSURE COOKER) TO INCREASE THE PROPORTION OF COOKING THAT CAN BE DONE ON A SINGLE APPLIANCE.

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Figure 6: The 3 energy-efficient cooking appliances on display at a focus group in Moshi. From left to right: the Electric Pressure Cooker (EPC), the rice cooker & the thermo-pot.

VOLTAGE HAS A MASSIVE IMPACT ON POWER & THEREFORE HEAT DELIVERED BY A COOKING APPLIANCE. IT IS LIKELY THAT CONSUMERS WHO HAVE TRIED COOKING WITH ELECTRICIAL APPLIACNES ON WEAK GRIDS WITH FLUCTUATING VOLTAGE WILL FIND THE EXPERIENCE OF COOKING BATTERY-SUPPORTED ELECTRICICTY VIA AN INVERTER MUCH MORE PREDICTABLE, AS AN INVERTER PRODUCES A CONSTANT VOLTAGE (UNTIL THE BATTERY RUNS OUT!).

Due to the maximum power limitation of the inverter/charger, it was only possible to power one appliance at a time. However, multiple appliances could cook at the same time as the pressure cooker is insulated, so retains heat well and only uses power occasionally to top up the internal temperature.

The inverter had a maximum power limit of 800W, but it was possible to use the 850W rated pressure cooker, as the output voltage could be manually lowered, effectively downrating the power consumed by each appliance. An 800W inverter/charger was selected purely because of the constraints of availability of LiFePO4 compatible components in East Africa. A 1.2kW inverter would have allowed the majority of off-the-shelf single plate electric cooking appliances to be used without having to downrate the voltage. However, the 1.5mm2 cables in the batteries would likely have become overloaded with 50% extra power, meaning that more batteries or batteries with proper terminals would have been needed.

Low power DC appliances could be connected via the solar controller. Either to the 12V port or the 5V USB. A 2W LED light and multi-plug USB phone charger from the Orb Energy solar home system was left plugged into the solar controller

The solar controller could display PV voltage, battery voltage and PV input current. The battery voltage display enables the user to know how much energy is left in the batteries. However, this is challenging with LiFePO4 batteries, as the voltage/state of charge curve is much flatter than lead acid, meaning that unless the batteries are almost completely charged or discharged, the voltage remains almost the same.

DC APPLIANCES ARE LIKELY TO COOK FASTER WHEN THE BATTERY IS FULL (13.6V FOR LIFEPO4) THAN WHEN EMPTY (9-10V FOR LIFEPO4). THE POWER PRODUCED BY A RESISTIVE HEATER IS PROPORTIONAL TO THE SQUARE OF THE VOLTAGE, SO A 25% DROP IN VOLTAGE EQUATES TO A 44% DROP IN POWER. FORTUNATELY THE RELATIVELY FLAT VOLTAGE/STATE-OF-CHARGE CURVE FOR LIFEPO4 MEANS THE HEAT SUPPLIED BY THE STOVE IS ONLY LIKELY TO VARY SIGNIFICANTLY WHEN ALMOST FULL OR ALMOST EMPTY. INSULATED APPLIANCES ARE ALSO LIKELY TO MITIGATE THIS EFFECT, AS HEAT IS RETAINED INSIDE THE POT FROM EARLIER IN THE COOKING PROCESS WHEN THE VOLTAGE WAS HIGHER.

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2 AC plug-in energy meters from the cooking diaries were supplied with the prototype. These could be used to measure the energy consumed by each appliance during demonstrations and by subtraction, what is left in the battery bank. They can also be used to measure how much energy has been drawn from the grid to charge the batteries via the inverter/charger.

3.6 Energy storage

The prototype was capable of cooking a meal for 5 people during a demonstration, as long as the cook cooked efficiently. For example, cooking 1/2kg of dry Rosecoco beans without putting the lid on the pressure cooker is likely to take several hours and use in excess of 2kWh. However, the same beans could comfortably be cooked with less than 0.3kWh if using the pressure cooker as intended. In fact, almost any food can be cooked in the pressure cooker with 0.3kWh, meaning that even if only 0.8kWh were available, a two-dish meal could comfortably be cooked without recharging.

A 30A LiFePO4 compatible solar controller enabled the prototype to charge from solar arrays of up to 360W, which should charge the batteries in 3 hours of full sun. It was observed that to charge the batteries from a fully discharged state (low voltage disconnect tripping at 10.5V) consistently required 1.6-1.7kWh. When discharging, the capacity of the batteries was proportional to C-rate. This could have been due to the fact that the voltage/state of charge curve varies with C-rate. Heavier loads pull down the voltage further, yet the low voltage disconnect on the inverter was set at a constant value (10.5V), independent of loading. This is likely to cause batteries under heavy loads to trip out the inverter (and therefore end the test) earlier.

MEASURING THE STATE OF CHARGE OF A LITHIUM ION BATTERY IS MORE COMPLICATED THAN LEAD ACID, AS THE VOLTAGE/STAGE-OF-CHARGE CURVE IS MUCH FLATTER. FUTURE PROTOTYPES SHOULD AIM TO INCORPORATE SIMILAR STATE OF CHARGE INDICATORS TO MOBILE PHONES OR LAPTOPS (LIKELY COULOMBIC COUNTING AND LEARNING ALGORITHMS TO DETECT CAPACITY FROM FULL CYCLES), WHICH ALSO USE LITHIUM ION BATTERIES. THESE MAY NEED TO REFLECT THE INFLUENCES OF HIGHER C-RATES.

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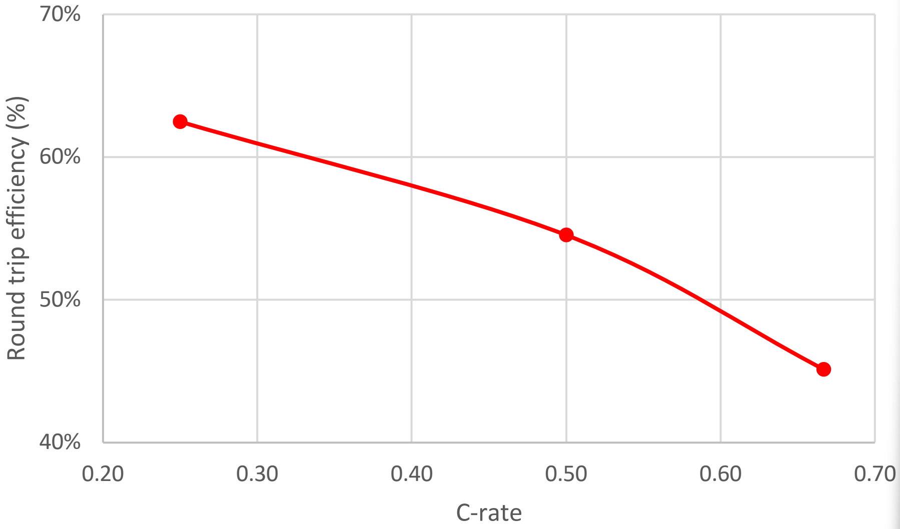
Figure 7: Relationship between C-rate and useful energy available from the batteries.



THE RELATIONSHIP BETWEEN C-RATE & USEFUL ENERGY AVAILABLE FROM THE BATTERIES SHOULD BE INVESTIGATED FURTHER. UNTIL DC COOKING APPLIANCES BECOME AVAILABLE, OPTIMISING THE LOW VOLTAGE DISCONNECT POINT FOR INVERTERS COULD GREATLY INCREASE USABLE STORAGE.

3.7 Communication

The prototype was successfully used to demonstrate the concept of cooking with batteries at several stakeholder events and focus groups. It could be demonstrated in two modes: ‘on-the-table’ and ‘under-the-table’. ‘On-the-table’ mode involved taking the plywood board with the main components mounted on it out of the box and displaying them on top of the table to explain what each component does. ‘Under-the-table’ mode was simply closing the lid of the box, with only the 3-way extension cable reaching above the table. In this mode, the focus is on the appliances and demonstrating how each one works. A variation on the latter is ‘on-top-of-the-box’ mode, where the box can be used as the table in case one is not available.

EVEN AT A LOW C-RATE (C/4), ROUND TRIP EFFICIENCIES WERE LOWER THAN EXPECTED (63%). FURTHER WORK IS REQUIRED TO DETERMINE WHERE THE INEFFICIENCIES ARE & TO OPTIMISE THE SYSTEM.

Figure 8: 'On-the-table' mode, allowing demonstrators to explain how the system works.

FUTURE PROTOTYPES SHOULD ALSO HAVE 2 MODES: ONE THAT ALLOWS MORE TECHNICAL PEOPLE TO SEE INSIDE AND ANOTHER THAT SHUTS AWAY THE GUBBINS AND ALLOWS THE USER TO GET ON WITH COOKING.

Figure 9: 'Under-the-table' mode (with lid off for the photo), allowing the cook to use the prototype as if the appliances were connected to the grid.

Figure 10: 'On-top-of-the-box' mode, allowing demonstrators to use the box itself as the table.

At the time of writing,, the protoype has already been demonstrated at several events, including:

- Focus group discussions in Kifuru, Kibindu, Moshi and Ubungo (Figure 11, Figure 12, Figure 13).
- Kitchen laboratory sessions at various locations around Dar es Salaam (Figure 14)
- eCook TZ stakeholder workshop at TaTEDO, Dar es Salaam (Figure 15).
- Awareness raising and demonstrations on efficient energy technologies (improved charcoal stoves, solar, briquettes and eCook) in Utete, Rufiji District (Figure 16).
- World Environment Week Exhibitions, Dar es Salaam (Figure 4).
- A policy advocacy workshop with a parliamentary select committee on energy (Figure 1) in Dodoma.

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Figure 11: The eCook TZ Mark 1 Prototype on show at a focus group in Ubungo, Dar es Salaam.

Figure 12: The eCook TZ Mark 1 Prototype on show at a focus group in Kibindu.

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Figure 13: The eCook TZ Mark 1 Prototype on show at a focus group in Kifuru.

Figure 14: The eCook TZ Mark 1 Prototype on show at a kitchen laboratory session in Ubungo, Dar es Salaam.

Figure 15: The eCook TZ Mark 1 Prototype on show at a the eCook Tanzania 2018 Stakeholder Workshop in Dar es Salaam.

Figure 16: The eCook TZ Mark 1 Prototype on show at awareness raising and demonstrations on efficient energy technologies (improved charcoal stoves, solar, briquettes and eCook) in Utete, Rufiji District.

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4 Key learning points

The key learning points from this prototyping experience are:

- Round trip efficiency is much lower than expected, especially at high C rates: (1.6kWh goes in, but only 0.8kWh comes out!) This could be partially addressed by using a low voltage disconnect that adjusts with C-rate.
- Appliances of up to 1,000W can be used on an 800W inverter by lowering the output voltage
- Maximum discharge current of LiFePO4 batteries is limited by the components in the BMS as much as the chemistry of the battery itself.
- Chargers designed for lead acid can charge some LiFePO4 batteries, but will not reach 100% state of charge, as they lower the voltage in the float stage of the charging cycle. LiFePO4 does not require float charging. Further research is needed to determine whether this is applicable to all LiFePO4 battery packs and what the impacts of doing this are on cycle life.
- Using multiple LiFePO4 battery packs in parallel is not recommended, but may again be necessary until supply chains develop further. If so:
    - The low voltage disconnect on inverters should be set to 10.5V instead of 9.5V to avoid the BMS in individual batteries cutting out.
    - MCBs or other resettable devices should be used instead of specialist fuses that must be replaced each time overcurrent occurs.
    - Battery packs with terminals rather than thin cables are more appropriate for high C-rate discsharge.
- You can cook with more than one appliance at a time, especially if they are insulated, by alternating power between them.
- Coulombic counting would give a much better indication of the SoC than voltage, but it would have to correct for C-rate.
- Component selection was restricted by the availability of LiFePO4 batteries and compatible hardware in East Africa. This is expected to improve in the coming years.
- If LiFePO4 chargers had been available, buying a standard inverter (without charging functionality) and using both devices to charge and discharge the battery bank respectively would likely have been a cheaper option.
- The box could be carried by one strong person, but its size and weight leave considerable room for improvement. This could be achieved by:

- Totally cutting out the inverter by using DC appliances plus a LiFePO4 charger would be much more efficient, compact, reliable and affordable.
- Selecting a single appliance that can cook a broad range of foods efficiently, i.e. the EPC.

5 Conclusion

A functional demonstration system was assembled to successfully communicate the concept of battery-supported cooking. However, the prototyping carried out in Tanzania showed that in 2018, although many of the basic components required to build a cost-effective and technically optimised eCook system were still not available. In particular, higher capacity lithium ion batteries and DC cooking appliances were very specialised pieces of equipment that required direct importation. However, a broad range of AC electric cooking appliances were available on the market and insulated appliances were selected as they offer substantial energy savings, which can greatly reduce the size of the battery. The eCook Tanzania prototype has been (and continues to be) very successful in demonstrating the concept of battery-supported cooking to key stakeholders.

The findings from this prototyping will be combined with those from the other activities that have been carried under the eCook Tanzania Market Assessment. Together they will build a more complete picture of the opportunities and challenges that await this emerging concept. Further outputs will be available from https://elstove.com/innovate-reports/ and www.MECS.org.uk.

6 Appendix

6.1 Appendix A: Problem statement and background to Innovate eCook project

6.1.1 Beyond business as usual

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 Billion people. This pervasive use of solid fuels—including wood, coal, straw, and dung—and traditional cookstoves results in high levels of household air pollution, extensive daily drudgery required to collect fuels, and serious health impacts. It is well known that open fires and primitive stoves are inefficient ways of converting energy into heat for cooking. The average amount of biomass cooking fuel used by a typical family can be as high as two tons per year. Indoor biomass cooking smoke also is associated with a number of diseases, including acute respiratory illnesses, cataracts, heart disease and even cancer. Women and children in particular are exposed to indoor cooking smoke in the form of small particulates up to 20 times higher than the maximum recommended levels of the World Health Organization. It is estimated that smoke from cooking fuels accounts for nearly 4 million premature deaths annually worldwide –more than the deaths from malaria and tuberculosis combined.

While there has been considerable investment in improving the use of energy for cooking, the emphasis so far has been on improving the energy conversion efficiency of biomass. Indeed in a recent overview of the state of the art in Improved Cookstoves (ICS), ESMAP & GACC (2015), World Bank (2014), note that the use of biomass for cooking is likely to continue to dominate through to 2030.

> *“Consider, for a moment, the simple act of cooking. Imagine if we could change the way nearly five hundred million families cook their food each day. It could slow climate change, drive gender equality, and reduce poverty. The health benefits would be enormous.” ESMAP & GACC (2015)*

The main report goes on to say that “The “business-as-usual” scenario for the sector is encouraging but will fall far short of potential.” (ibid,) It notes that without major new interventions, over 180 million

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households globally will gain access to, at least, minimally improved[2] cooking solutions by the end of the decade. However, they state that this business-as-usual scenario will still leave over one- half (57%) of the developing world's population without access to clean cooking in 2020, and 38% without even minimally improved cooking solutions. The report also states that 'cleaner' stoves are barely affecting the health issues, and that only those with forced gasification make a significant improvement to health. Against this backdrop, there is a need for a different approach aimed at accelerating the uptake of truly 'clean' cooking.

Even though improved cooking solutions are expected to reach an increasing proportion of the poor, the absolute numbers of people without access to even 'cleaner' energy, let alone 'clean' energy, will increase due to population growth. The new Sustainable Development Goal 7 calls for the world to "ensure access to affordable, reliable, sustainable and modern energy for all". Modern energy (electricity or LPG) would indeed be 'clean' energy for cooking, with virtually no kitchen emissions (other than those from the pot). However, in the past, modern energy has tended to mean access to electricity (mainly light) and cooking was often left off the agenda for sustainable energy for all.

Even in relation to electricity access, key papers emphasise the need for a step change in investment finance, a change from 'business as usual'. IEG World Bank Group (2015) note that 22 countries in the Africa Region have less than 25 percent access, and of those, 7 have less than 10 percent access. Their tone is pessimistic in line with much of the recent literature on access to modern energy, albeit in contrast to the stated SDG7. They discuss how population growth is likely to outstrip new supplies and they argue that "unless there is a big break from recent trends the population without electricity access in Sub-Saharan Africa is projected to increase by 58 percent, from 591 million in 2010 to 935 million in 2030." They lament that about 40% of Sub-Saharan Africa's population is under 14 years old and conclude that if the current level of investment in access continues, yet another generation of children will be denied the benefits of modern service delivery facilitated by the provision of electricity (IEG World Bank Group 2015).

> *"Achieving universal access within 15 years for the low-access countries (those with under 50 percent coverage) requires a quantum leap from their present pace of 1.6 million connections per year to 14.6 million per year until 2030." (ibid)*

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[2] A minimally improved stove does not significantly change the health impacts of kitchen emissions. "For biomass cooking, pending further evidence from the field, significant health benefits are possible only with the highest quality fan gasifier stoves; more moderate health impacts may be realized with natural draft gasifiers and vented intermediate ICS" (ibid)

Once again, the language is a call for a something other than business as usual. The World Bank conceives of this as a step change in investment. It estimates that the investment needed to really address global electricity access targets would be about $37 billion per year, including erasing generation deficits and additional electrical infrastructure to meet demand from economic growth. “By comparison, in recent years, low-access countries received an average of $3.6 billion per year for their electricity sectors from public and private sources” (ibid). The document calls for the Bank Group‘s energy practice to adopt a new and transformative strategy to help country clients orchestrate a national, sustained, sector-level engagement for universal access.

In the following paragraphs, we explore how increasing access to electricity could include the use of solar electric cooking systems, meeting the needs of both supplying electricity and clean cooking to a number of households in developing countries with sufficient income.

6.1.2 Building on previous research

Gamos first noted the trends in PV and battery prices in May 2013. We asked ourselves the question, is it now cost effective to cook with solar photovoltaics? The answer in 2013 was ‘no’, but the trends suggested that by 2020 the answer would be yes. We published a concept note and started to present the idea to industry and government. Considerable interest was shown but uncertainty about the cost model held back significant support. Gamos has since used its own funds to undertake many of the activities, as well as IP protection (a defensive patent application has been made for the battery/cooker combination) with the intention is to make all learning and technology developed in this project open access, and awareness raising amongst the electrification and clean cooking communities (e.g. creation of the infographic shown in Figure 17 to communicate the concept quickly to busy research and policy actors).

Gamos has made a number of strategic alliances, in particular with the University of Surrey (the Centre for Environmental Strategy) and Loughborough University Department of Geography and seat of the Low Carbon Energy for Development Network). In October 2015, DFID commissioned these actors to explore assumptions surrounding solar electric cooking[3] (Batchelor 2015b; Brown & Sumanik-Leary 2015; Leach & Oduro 2015; Slade 2015). The commission arose from discussions between consortium members, DFID, and a number of other entities with an interest in technological options for cleaner cooking e.g. Shell Foundation and the Global Alliance for Clean Cookstoves.

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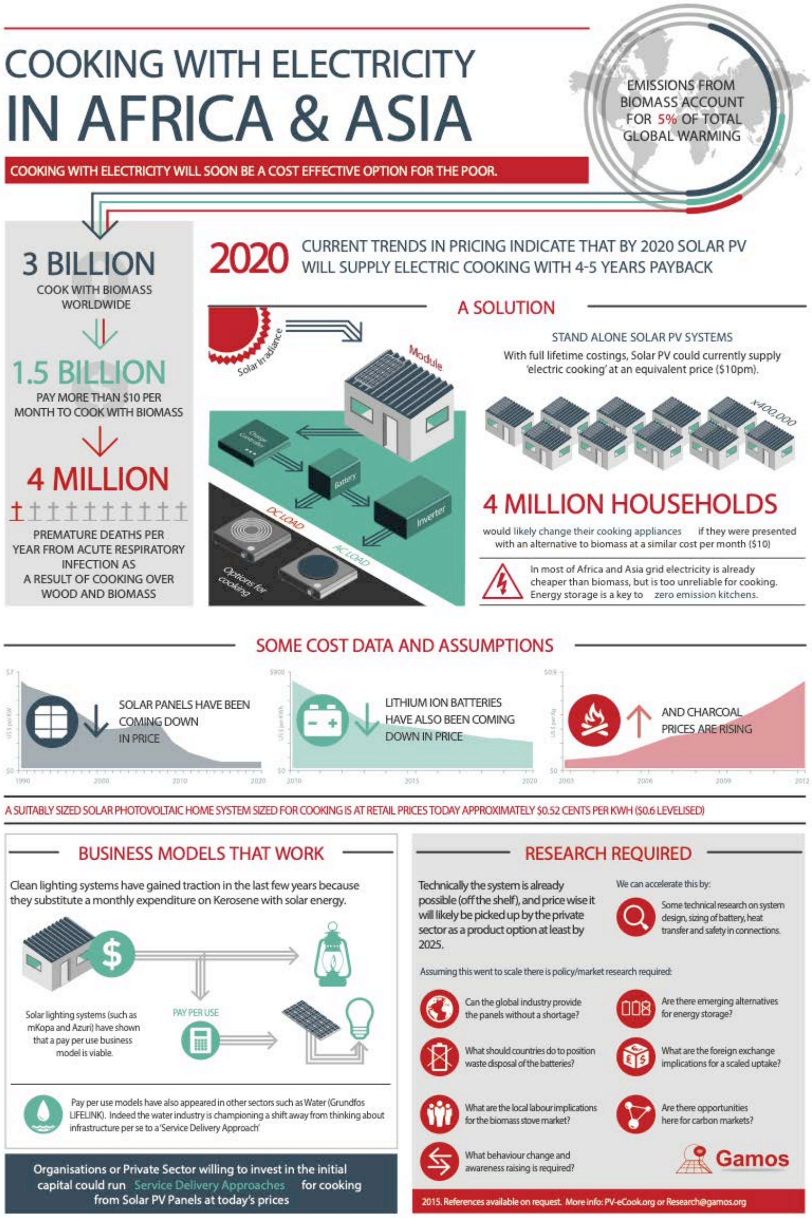
[3] The project has been commissioned through the PEAKS framework agreement held by DAI Europe Ltd.

Drawing on evidence from the literature, the papers show that the concept is technically feasible and could increase household access to a clean and reliable modern source of energy. Using a bespoke economic model, the Leach and Oduro paper also confirm that by 2020 a solar based cooking system could be comparable in terms of monthly repayments to the most common alternative fuels, charcoal and LPG. Drawing on published and grey literatures, many variables were considered (e.g. cooking energy needs, technology performance, component costs). There is uncertainty in many of the parameter values, including in the assumptions about future cost reductions for PV and batteries, but the cost ranges for the solar system and for the alternatives overlap considerably. The model includes both a conservative 5% discount rate representing government and donor involvement, and a 25% discount rate representing a private sector led initiative with a viable return. In both cases, the solar system shows cost effectiveness in 2020.



COOKING WITH ELECTRICITY
IN AFRICA & ASIA

COOKING WITH ELECTRICITY WILL SOON BE A COST EFFECTIVE OPTION FOR THE POOR.

EMISSIONS FROM BIOMASS ACCOUNT FOR 5% OF TOTAL GLOBAL WARMING

3 BILLION COOK WITH BIOMASS WORLDWIDE

1.5 BILLION PAY MORE THAN $10 PER MONTH TO COOK WITH BIOMASS

4 MILLION PREMATURE DEATHS PER YEAR FROM ACUTE RESPIRATORY INFECTION AS A RESULT OF COOKING OVER WOOD AND BIOMASS

2020 CURRENT TRENDS IN PRICING INDICATE THAT BY 2020 SOLAR PV WILL SUPPLY ELECTRIC COOKING WITH 4-5 YEARS PAYBACK

A SOLUTION

STAND ALONE SOLAR PV SYSTEMS

With full lifetime costings, Solar PV could currently supply 'electric cooking' at an equivalent price ($10pm).

4 MILLION HOUSEHOLDS would likely change their cooking appliances if they were presented with an alternative to biomass at a similar cost per month ($10)

In most of Africa and Asia grid electricity is already cheaper than biomass, but is too unreliable for cooking. Energy storage is a key to zero emission kitchens.

SOME COST DATA AND ASSUMPTIONS

SOLAR PANELS HAVE BEEN COMING DOWN IN PRICE

LITHIUM ION BATTERIES HAVE ALSO BEEN COMING DOWN IN PRICE

AND CHARCOAL PRICES ARE RISING

A SUITABLY SIZED SOLAR PHOTOVOLTAIC HOME SYSTEM SIZED FOR COOKING IS AT RETAIL PRICES TODAY APPROXIMATELY $0.52 CENTS PER KWH ($0.6 LEVELISED)

BUSINESS MODELS THAT WORK

Clean lighting systems have gained traction in the last few years because they substitute a monthly expenditure on Kerosene with solar energy.

Solar lighting systems (such as mKopa and Azuri) have shown that a pay per use business model is viable.

Pay per use models have also appeared in other sectors such as Water (Grundfos LIFELINK). Indeed the water industry is championing a shift away from thinking about infrastructure per se to a 'Service Delivery Approach'

Organisations or Private Sector willing to invest in the initial capital could run Service Delivery Approaches for cooking from Solar PV Panels at today's prices

RESEARCH REQUIRED

Technically the system is already possible (off the shelf), and price wise it will likely be picked up by the private sector as a product option at least by 2025.

We can accelerate this by:

Some technical research on system design, sizing of battery, heat transfer and safety in connections.

Assuming this went to scale there is policy/market research required:

- Can the global industry provide the panels without a shortage?
- What should countries do to position waste disposal of the batteries?
- What are the local labour implications for the biomass stove market?
- What behaviour change and awareness raising is required?
- Are there emerging alternatives for energy storage?
- What are the foreign exchange implications for a scaled uptake?
- Are there opportunities here for carbon markets?

2015. References available on request. More info: PV-eCook.org or Research@gamos.org

Figure 17 Infographic summarising the concept in order to lobby research and policy actors.

The Brown and Sumanik-Leary paper in the series examines the lessons learned from four transitions – the uptake of electric cooking in South Africa, the roll out of Improved Cookstoves (ICS), the use of LPG and the uptake of Solar Home Systems (SHS). They present many behavioural concerns, none of which preclude the proposition as such, but all of which suggest that any action to create a scaled use of solar electric cooking would need in depth market analysis; products that are modular and paired with locally appropriate appliances; the creation of new, or upgrading of existing, service networks; consumer awareness raising; and room for participatory development of the products and associated equipment.

A synthesis paper summarising the above concludes by emphasising that the proposition is not a single product – it is a new genre of action and is potentially transformative. Whether solar energy is utilised within household systems or as part of a mini, micro or nano grid, linking descending solar PV and battery costs with the role of cooking in African households (and the Global South more broadly) creates a significant potential contribution to SDG7. Cooking is a major expenditure of 500 million households. It is a major consumer of time and health. Where households pay for their fuelwood and charcoal (approximately 300 Million) this is a significant cash expense. Solar electric cooking holds the potential to turn this (fuelwood and charcoal) cash into investment in modern energy. This "consumer expenditure" is of an order of magnitude more than current investment in modern energy in Africa and to harness it might fulfil the calls for a step change in investment in electrical infrastructure.

6.1.3 Summary of related projects

A series of inter-related projects have led to and will follow on from the research presented in this report:

- Gamos Ltd.'s early conceptual work on eCook (Batchelor 2013).
  - The key **CONCEPT NOTE** can be found here.
  - An early infographic and a 2018 infographic can be found here.
- Initial technical, economic and behavioural feasibility studies on eCook commissioned by DfID (UK Aid) through the CEIL-PEAKS Evidence on Demand service and implemented by Gamos Ltd., Loughborough University and University of Surrey.
  - The key **FINAL REPORTS** can be found here.
- Conceptual development, stakeholder engagement & prototyping in Kenya & Bangladesh during the "*Low cost energy-efficient products for the bottom of the pyramid*" project from the USES programme funded by DfID (UK Aid), EPSRC & DECC (now part of BEIS) & implemented by University of Sussex, Gamos Ltd., ACTS (Kenya), ITT & UIU (Bangladesh).
  - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- A series of global & local market assessments in Myanmar, Zambia and Tanzania under the "*eCook - a transformational household solar battery-electric cooker for poverty alleviation*" project funded by DfID (UK Aid) & Gamos Ltd. through Innovate UK's Energy Catalyst Round 4, implemented by Loughborough University, University of Surrey, Gamos Ltd., REAM (Myanmar), CEEEZ (Zambia) & TaTEDO (Tanzania).
  - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- At time of publication (Q1 2019), a new DfID (UK Aid) funded research programme '*Modern Energy Cooking Services*' (MECS) lead by Prof. Ed Brown at Loughborough University is just beginning and will take forward these ideas & collaborations.

This data and material have been funded by UK AID from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

6.1.4 About the Modern Energy Cooking Services (MECS) Programme.

Sparking a cooking revolution: catalysing Africa's transition to clean electric/gas cooking.

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Modern Energy Cooking Services (MECS) is a five-year research and innovation programme funded by UK Aid (DFID). MECS hopes to leverage investment in renewable energies (both grid and off-grid) to address the clean cooking challenge by integrating modern energy cooking services into the planning for access to affordable, reliable and sustainable electricity.

Existing strategies are struggling to solve the problem of unsustainable, unhealthy but enduring cooking practices which place a particular burden on women. After decades of investments in improving biomass cooking, focused largely on increasing the efficiency of biomass use in domestic stoves, the technologies developed are said to have had limited impact on development outcomes. The Modern Energy Cooking Services (MECS) programme aims to break out of this "business-as-usual" cycle by investigating how to rapidly accelerate a transition from biomass to genuinely 'clean' cooking (i.e. with electricity or gas).

Worldwide, nearly three billion people rely on traditional solid fuels (such as wood or coal) and technologies for cooking and heating[4]. This has severe implications for health, gender relations, economic livelihoods, environmental quality and global and local climates. According to the World Health Organization (WHO), household air pollution from cooking with traditional solid fuels causes to 3.8 million premature deaths every year – more than HIV, malaria and tuberculosis combined[5]. Women and children are disproportionally affected by health impacts and bear much of the burden of collecting firewood or other traditional fuels.

Greenhouse gas emissions from non-renewable wood fuels alone total a gigaton of CO_2e per year (1.9-2.3% of global emissions)[6]. The short-lived climate pollutant black carbon, which results from incomplete combustion, is estimated to contribute the equivalent of 25 to 50 percent of carbon dioxide warming

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[4] http://www.who.int/indoorair/health_impacts/he_database/en/

[5] https://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health https://www.who.int/gho/hiv/epidemic_status/deaths_text/en/, https://www.who.int/en/news-room/fact-sheets/detail/malaria, https://www.who.int/en/news-room/fact-sheets/detail/tuberculosis

[6] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

globally – residential solid fuel burning accounts for up to 25 percent of global black carbon emissions[7]. Up to 34% of woodfuel harvested is unsustainable, contributing to climate change and local forest degradation. In addition, approximately 275 million people live in woodfuel depletion 'hotspots' – concentrated in South Asia and East Africa – where most demand is unsustainable[8].

Africa's cities are growing – another Nigeria will be added to the continent's total urban population by 2025[9] which is set to double in size over the next 25 years, reaching 1 billion people by 2040. Within urban and peri-urban locations, much of Sub Saharan Africa continues to use purchased traditional biomass and kerosene for their cooking. Liquid Petroleum Gas (LPG) has achieved some penetration within urban conurbations, however, the supply chain is often weak resulting in strategies of fuel stacking with traditional fuels. Even where electricity is used for lighting and other amenities, it is rarely used for cooking (with the exception of South Africa). The same is true for parts of Asia and Latin America. Global commitments to rapidly increasing access to reliable and quality modern energy need to much more explicitly include cooking services or else household and localized pollution will continue to significantly erode the well-being of communities.

Where traditional biomass fuels are used, either collected in rural areas or purchased in peri urban and urban conurbations, they are a significant economic burden on households either in the form of time or expenditure. The McKinsey Global Institute outlines that much of women's unpaid work hours are spent on fuel collection and cooking[10]. The report shows that if the global gender gap embodied in such activities were to be closed, as much as $28 trillion, or 26 percent, could be added to the global annual GDP in 2025. Access to modern energy services for cooking could redress some of this imbalance by releasing women's time into the labour market.

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[7] http://cleancookstoves.org/impact-areas/environment/

[8] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

[9] https://openknowledge.worldbank.org/handle/10986/25896

[10] McKinsey Global Institute. *The Power of Parity: How Advancing Women's Equality can add $12 Trillion to Global Growth;* McKinsey Global Institute: New York, NY, USA, 2015.

To address this global issue and increase access to clean cooking services on a large scale, investment needs are estimated to be at least US$4.4 billion annually[11]. Despite some improvements in recent years, this cross-cutting sector continues to struggle to reach scale and remains the least likely SE4All target to be achieved by 2030[12], hindering the achievement of the UN's Sustainable Development Goal (SDG) 7 on access to affordable, reliable, sustainable and modern energy for all.

Against this backdrop, MECS draws on the UK's world-leading universities and innovators with the aim of sparking a revolution in this sector. A key driver is the cost trajectories that show that cooking with (clean, renewable) electricity has the potential to reach a price point of affordability with associated reliability and sustainability within a few years, which will open completely new possibilities and markets. Beyond the technologies, by engaging with the World Bank (ESMAP), MECS will also identify and generate evidence on other drivers for transition including understanding and optimisation of multi-fuel use (fuel stacking); cooking demand and behaviour change; and establishing the evidence base to support policy enabling environments that can underpin a pathway to scale and support well understood markets and enterprises.

The five-year programme combines creating a stronger evidence base for transitions to modern energy cooking services in DFID priority countries with socio-economic technological innovations that will drive the transition forward. It is managed as an integrated whole; however, the programme is contracted via two complementary workstream arrangements as follows:

- An Accountable Grant with Loughborough University (LU) as leader of the UK University Partnership.
- An amendment to the existing Administrative Arrangement underlying DFID's contribution to the ESMAP Trust Fund managed by the World Bank.

The intended outcome of MECS is a market-ready range of innovations (technology and business models) which lead to improved choice of affordable and reliable modern energy cooking services for consumers.

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[11] The SE4ALL Global Tracking Report shows that the investment needed for universal access to modern cooking (not including heating) by 2030 is about $4.4 billion annually. In 2012 investment was in cooking was just $0.1 billion. Progress toward Sustainable Energy: Global Tracking Report 2015, World Bank.

[12] The 2017 SE4All Global Tracking Framework Report laments that, "Relative to electricity, only a small handful of countries are showing encouraging progress on access to clean cooking, most notably Indonesia, as well as Peru and Vietnam."

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Figure 18 shows how the key components of the programme fit together. We will seek to have the MECS principles adopted in the SDG 7.1 global tracking framework and hope that participating countries will incorporate modern energy cooking services in energy policies and planning.

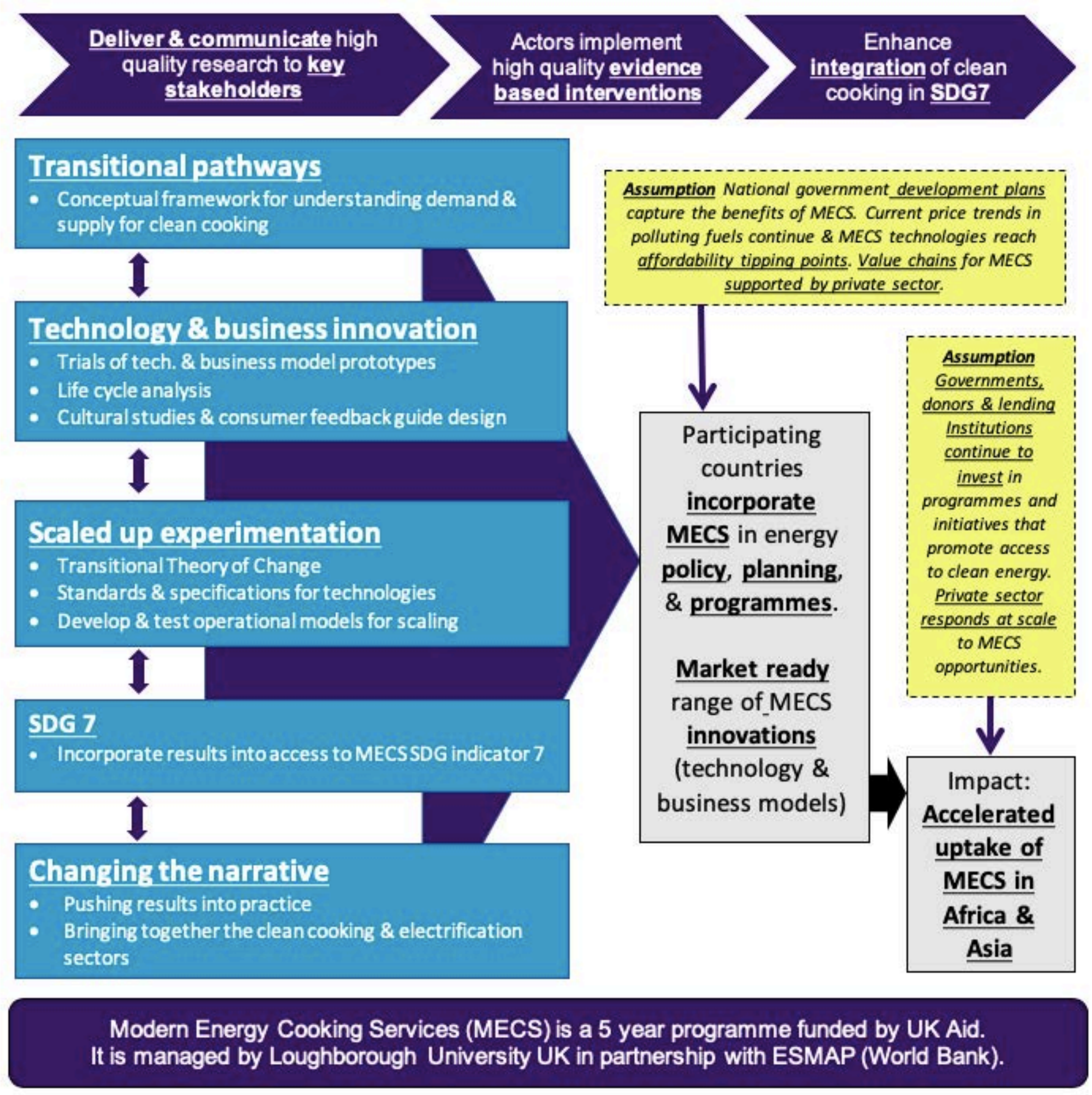

Figure 18: Overview of the MECS programme.